

# Application of CSRR Metamaterial in Antenna

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**Abstract**—The paper talks about a compact patch antenna design at 3 GHz. A novel complementary square ring resonator as DNG metamaterial has been modeled and designed for its resonance at 3 GHz. The designed metamaterial provides negative real permeability and permittivity over a wide frequency band, making it suitable for its applications in patch size reduction. The effect of loading the metamaterial shows a patch dimensional space reduction (from 26.1 mm x 26.1 mm to 17.6 mm x 17.6 mm) of about 54.53 % while providing the similar gain and efficiency. The patch antenna without loading the metamaterial and loaded with the metamaterial provides a similar radiation efficiency and angular width however there is some difference in gain and the bandwidth of its operation. The proposed antenna is perfectly suited for its integration into flexible and wearable electronics design.

**Keywords**—Patch, Antenna, Flexible, CSRR, 3 GHz

## I. INTRODUCTION

The arrival of wearable electronics for its wide ranging applications in real time signal transmission and monitoring has created new opportunity for the design of flexible and compact size electronics components. A key feature of the wearable electronics is its communication over wireless media using compact antenna across its devices. However the antenna needs to be small, compact and still flexible while providing good radiation and gain within the intended operating frequency. The paper talks about a flexible microstrip patch antenna design working at 3 GHz with the use of a thin polyimide substrate (1.6 mm) and very fine layer (1  $\mu$ m) of the conducting media at signal and ground layer. The microstrip patch antenna size is in the order of half wavelength however with the loading of a Double Negative (DNG) metamaterial, it can resonate at its sub-wavelength [1 – 2]. Past studies have shown the patch miniaturization using high permittivity substrate [3 – 4], dielectric loading [5], DNG metamaterial [6 – 10] however this paper talks about the loading of the Complementary square ring resonator (CSRR) for a compact patch antenna with its corner cut across its diagonal. The corner cut of the patch antenna provides an increase in its bandwidth over the same size patch antenna. The effect of a DNG metamaterial over a traditional patch antenna for its antenna parameters such as reflection coefficient, directivity, gain and radiation efficiency at 3 GHz has been evaluated and compared. The modeling and simulation result has been obtained using CST Microwave studio (3D field solver tool) while various plots such as permittivity, permeability behaviour, S11 and S12 parametric comparison have been obtained using Matlab.

## II. DESIGN METHODOLOGY

### A. CSRR Design

A CSRR metamaterial has been designed for its application at 3 GHz and is shown in Fig. 1. The square ring patch shows two concentric square rings with the outer dimension of the ring being 7.5 mm, the width of the ring being 0.7 mm and the spacing between two rings being 0.8 mm while its thickness is 0.001 mm. The square rings are cut in their complementary positions with 0.25 mm x 0.7 mm x 0.0001 mm dimension while the substrate spacing 's' is 0.4 mm. The rings are designed using copper and is laid over a 8.3 mm x 8.3 mm x 1.6 mm polyimide substrate (dielectric constant of 3.5 and tangent loss of 0.0027).

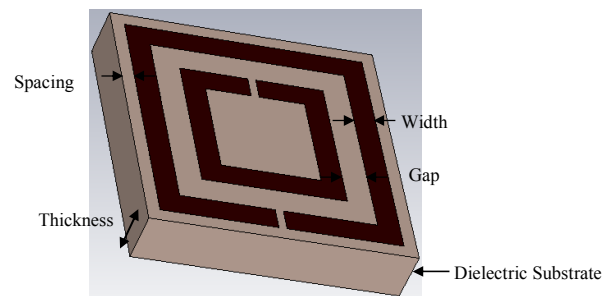


Fig. 1 Patch antenna

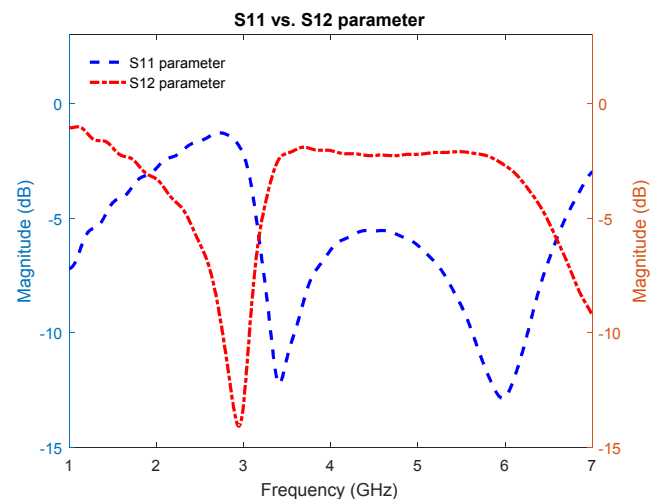


Fig. 2 S11 and S12 parameter for CSRR metamaterial

The S11 and S12 parameters for the CSRR structure have been obtained and shown in Fig. 2. The S11 and S12 parameter along with the CSRR structure dimensions have been used to find the effective permittivity and permeability using the analytical functions (1) – (5) [11 – 12] and its Matlab plot is shown in Fig. 3. Here  $\epsilon$  and  $\mu$  represent the permittivity and permeability of the designed structure while S11, S12, d, n and z are S-parameters, thickness of the metamaterial, refractive index and intrinsic impedance. As shown here the relative permittivity and permeability is negative within the intended frequency range, thus the metamaterial behaves as DNG metamaterial structure.

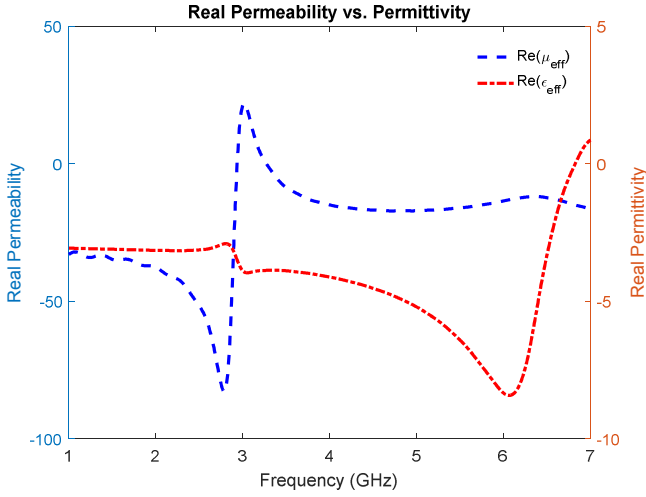


Fig. 3 Real Permeability and permittivity plot for CSRR

$$z = \sqrt{\frac{(1 + S_{11})^2 - S_{21}^2}{(1 - S_{11})^2 - S_{21}^2}} \quad (1)$$

$$e(jn k_0 d) = A \pm j\sqrt{(1 - A^2)} \quad (2)$$

$$A = \frac{(1 - S_{11}^2 + S_{21}^2)}{(2 S_{21})} \quad (3)$$

$$\epsilon = n/z \quad (4)$$

$$\mu = n \times z \quad (5)$$

### B. Patch Antenna Design

The CST software has been used to model and simulate the patch antenna. A patch antenna using copper as its conducting media without loading the CSRR and operating at 3 GHz has been designed and is shown in Fig. 4. Similarly Figs. 5 and 6 show the antenna patch with loading the CSRR. The patch has a dimension of 26.1 mm x 26.1 mm x 0.001 mm with a corner cut of 5 mm x 5 mm x 0.001 mm at its diagonal. It is laid over a polyimide substrate with 51.7 mm x 53.9 mm x 1.6 mm and substrate is laid over a PEC media with a thickness of 0.001 mm and 51.7 mm x 53.9 mm size. The conducting patch is connected through a feed of 15 mm x 3.6 mm x 0.001.

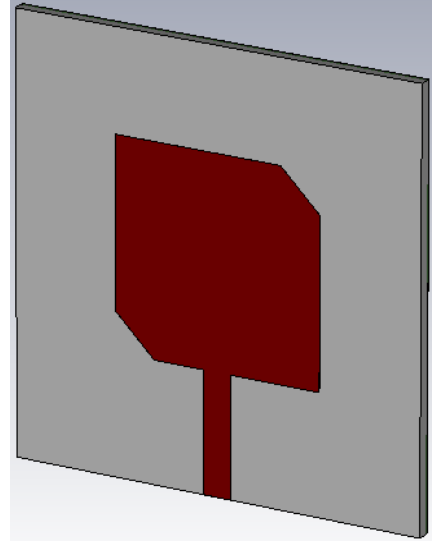


Fig. 4 Patch antenna without CSRR loading

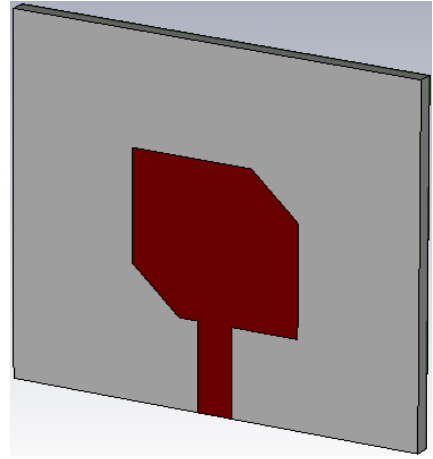


Fig. 5 Patch antenna with CSRR loading (top layer)

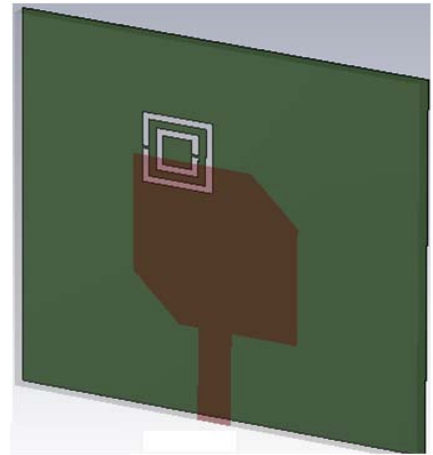


Fig. 6 Patch antenna with CSRR loading (Bottom layer)

Similarly a patch antenna using copper as its conducting media with loading the CSRR metamaterial has been designed for its resonance at 3 GHz. The patch has a dimension of 17.6

mm x 17.6 mm x 0.001 mm with a corner cut of 5 mm x 5 mm across its diagonal. It is laid over a 43.2 mm x 40.4 mm x 1.6 mm polyimide substrate and the substrate is laid over a PEC media. The conducting patch is connected through a feed of 10 mm x 3.6 mm x 0.001 mm. The metamaterial dimension as described in its previous section has been used here at the ground plane of the patch antenna. The metamaterial is placed at -5 mm in x- direction and 9 mm in y- direction from the patch origin.

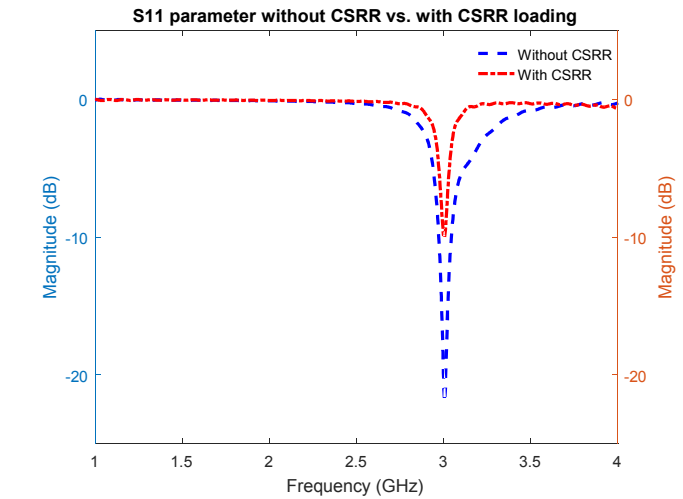


Fig. 7 Comparison of S11 parameter

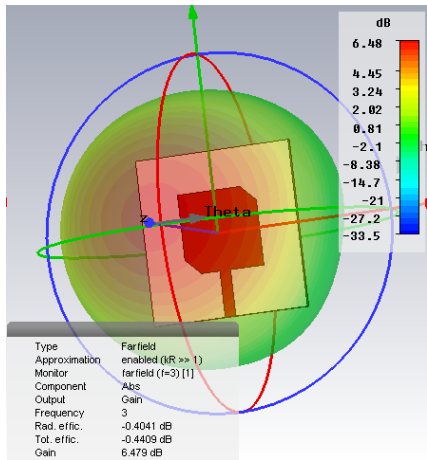


Fig. 8 Radiation diagram for the patch antenna without CSRR

Fig. 7 shows a comparison of the S11 parameter for the patch antenna loaded with CSRR structure and the patch without loading the CSRR structure. The patch antenna without loading the CSRR structure provides -22 dB reflectivity with 71.9 MHz bandwidth while the loaded patch antenna provides -10.10 dB reflectivity with 1.9 MHz bandwidth. The radiation diagram of the patch antenna without loading the CSRR structure and with loading the CSRR structure have been shown in Figs. 8 and 9.

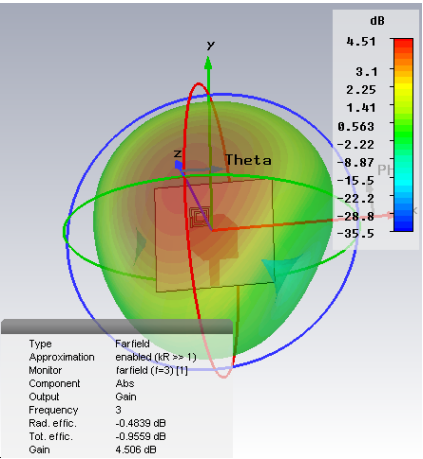


Fig. 9 Radiation diagram for the patch antenna with CSRR

### III. COMPARISON OF PARAMETRS

Table I shows the comparison of antenna parameters such as reflection coefficient, VSWR, Gain, Directivity and efficiency with and without CSRR metamaterial loading. As shown here, the patch antenna without loading CSRR structure provides higher gain, directivity and bandwidth while the radiation efficiency from these patch structures are nearly the same. Both the structure resonates at 3 GHz while the CSRR loaded structure provides a significant patch size reduction.

TABLE I  
COMPARISON OF PATCH ANTENNAS

	Freq (f <sub>0</sub> ) in GHz	Bandwidth (MHz)	S11 (dB)	VSWR
Without CSRR	3	71.9	-22.00	1.17
With CSRR	3	1.9	-10.10	1.92
	Directivity (dBi)	Gain (dB)	Angular width (°)	Radiation Efficiency (%)
Without CSRR	6.88	6.48	45.2	91.11
With CSRR	4.99	4.51	45.4	89.46

### IV. CONCLUSION

The paper describes about the modeling and design of a compact patch antenna resonating at 3 GHz. The use of polyimide as substrate makes its application in wearable electronics while miniaturization of the patch antenna with the loading of CSRR metamaterial in addition may provide its application in medical electronics apart from wearable and automotive applications. The loading of a CSRR metamaterial provides a size reduction (from 26.1 mm to 17.6 mm) of about 32.57 % and a dimensional space reduction of about 54.53 %.

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